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ENVIRONMENTALLY DEPENDENT COUNTERMEASURES TO PASSIVE INFRARED DETECTION

December 1998

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ABSTRACT

Simple countermeasures against passive (thermal) infrared intrusion detection systems (IDSs) and thermal imagers were tested in winter by U.S. Army Special Forces soldiers working with personnel of the U. S. Army Cold Regions Research and Engineering Laboratory (CRREL). Under certain site conditions, the countermeasures were very effective, enabling intruders to pass undetected by the infrared IDSs or unnoticed by observers viewing thermal imagery of the site. An awareness of the interplay between environment, countermeasure, and sensor system is crucial both in identifying when a sensor system is vulnerable to countermeasures and in selecting the appropriate countermeasure. This paper explains which environmental factors during the Special Forces / CRREL intrusions determined the success or failure of a countermeasure. It also predicts the general effectiveness of similar countermeasures as a function of the operating environment of a thermal infrared sensor system.

1.0 INTRODUCTION

Winter commonly is thought to provide conditions advantageous for the detection of intruders with thermal infrared sensor systems. The expectation is that outdoors in winter a person remains sufficiently warmer than his environment that there is adequate thermal contrast for him to be reliably detected by a passive infrared (PIR) intrusion detection system (IDS) and to be readily observable in thermal imagery. For instance, calibrated thermal imagery of a person climbing a chain-link fence one clear winter day at the CRREL IDS site documents that the temperature of the intruder's face was at least 15°C, his hat and trousers were 10°C, and his jacket 5°C, while the surface of the snow cover was –7°C, the trunks of trees beyond the fence were –4°C and the sky temperature was less than –9°C. The intruder's thermal contrast ranged from 9°C to greater than 14°C, depending on the portion of his body being viewed against a background of snow, trees, or sky.

Strong inherent thermal contrast, such as that of an intruder against a snowcover, however, does not ensure detection in winter. In the presence of rain, fog, or falling snow, the intruder's apparent thermal contrast at the IDS or imager may be below detection level. For a 100-m path length, the transmission loss due to scattering and absorption of infrared radiation is 10% in rain (8 mm / hr precipitation rate), 25% in light to moderate radiation fog, 95% in heavy advection fog, and 55% in a moderate-intensity snowstorm (0.4 g / m^3 snow mass concentration). Among other factors, the severity of extinction depends on the cumulative cross-section of the water droplets or snowflakes in a volume of air, so transmission

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1. REPORT DATE (DD-MM-YYYY)
01-12-1998

2. REPORT TYPE
Conference Proceedings

3. DATES COVERED (FROM - TO)
xx-xx-1998 to xx-xx-1998

4. TITLE AND SUBTITLE
Environmentally Dependent Countermeasures to Passive Infrared Detection
Unclassified

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Peck, Lindamae ;
Lacombe, James ;

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME AND ADDRESS
US Army Cold Regions Research and Engineering Laboratory
Hanover, NH03755

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME AND ADDRESS
Director, CECOM RDEC
Night Vision and Electronic Sensors Directorate
10221 Burbeck Road
Ft. Belvoir, VA22060-5806

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
APUBLIC RELEASE
,

13. SUPPLEMENTARY NOTES
See Also ADM201041, 1998 IRIS Proceedings on CD-ROM.

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15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:

a. REPORT	b. ABSTRACT	c. THIS PAGE
Unclassified	Unclassified	Unclassified

17. LIMITATION OF ABSTRACT
Public Release

18. NUMBER OF PAGES
13

19. NAME OF RESPONSIBLE PERSON
Fenster, Lynn
lfenster@dtic.mil

19b. TELEPHONE NUMBER
International Area Code
Area Code Telephone Number
703767-9007
DSN
427-9007

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39.18

loss may be different in storms of nominally the same precipitation rate or snow mass concentration. This introduces uncertainty as to whether an intruder can rely upon the effects of bad weather to render him undetectable.

To improve his chances for avoiding detection by a PIR IDS or for passing unnoticed in thermal imagery, the intruder may resort to countermeasures. U.S. Army Special Forces soldiers, in their role as high-threat intruders against the sensor systems at an IDS field site operated by CRREL, were challenged to create countermeasures against thermal detection. They were allowed to use items available from the local hardware store, provided that the resultant countermeasure was practical enough for them to carry it on a mission. Countermeasure effectiveness was tested with intrusions against a PIR IDS with and without the countermeasure in use. Whether the intruder using a countermeasure avoided detection depended strongly on the site conditions during his intrusion, although no intrusions were conducted in fog, rain, or steady snowfall. The lesson learned by the intruders is that a sensor system's operating environment must be considered when evaluating the system's vulnerability to countermeasure-aided intrusions.

2.0 PASSIVE INFRARED INTRUSION DETECTION SYSTEM

The thermal countermeasures were used against an Eltec 862-71C IR-Eye Long-Range Passive Infrared Telescope intrusion detection system (Figure 1). The PIR IDS is mounted on a tripod at a height of 3 m and angled slightly below horizontal, so that its detection zone terminates at ~50 m. The PIR has two infrared detectors (8–14 µm spectral band) with different but closely spaced fields of view (Figure 2). Each field of view covers a triangular sector of ground 50 m long and ~0.25 m wide at its farthest extent. The net radiance from this sector determines the detector's response. The output of these detectors is wired in a parallel-opposed manner so that a simultaneous, similar change in received thermal radiance at its two detectors produces no net response by the PIR, while a differential change of input to its two detectors causes a response determined jointly by the magnitude and the rate of change of the received thermal radiance. The PIR electronics are designed to respond to rapid changes in thermal radiance with peak response of the thermal detectors at 1 Hz.

The PIR generates a voltage that is an index of the similarity of changes in thermal radiance throughout the two sectors that comprise its intrusion detection zone. That voltage is compared with a second, constant voltage having a magnitude determined by the operator-selectable sensitivity of the PIR. The higher the PIR sensitivity setting, the smaller the difference between the net sensor voltage and the threshold voltage, and the higher the PIR's proximity to alarm (PTA). When the threshold voltage is exceeded, the PIR goes into alarm. If the PTA is high because of natural variation in the thermal radiance of objects in the PIR's detection zone, then even a relatively small thermal disturbance by the intruder may cause the PIR to alarm. High PTA situations leave the intruder only a small margin for avoiding detection.

Figure 1. Eltec PIR at IDS field site.

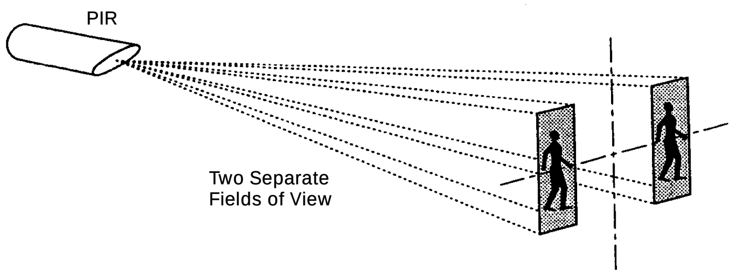

Figure 2. Discrete fields of view of PIR's two thermal detectors.

3.0 COUNTERMEASURES TO THERMAL DETECTION

Four countermeasures are described. The first two are worn by the intruder, the third is installed on the PIR, and the fourth is an expedient shelter against thermal detection. Apparent temperatures (°C) of the snow surface and sky are calculated from measurements of radiation (W/m^2) in the band 3 to 50 μm using the equation, T = 63.75* (radiation flux per unit area)$^{0.25}$ – 265.80. This is a linear regression fit to Planck's equation with the assumptions of black body emission of the snow (sky) and flat, 100% radiometer response over the 3 to 50 μm spectrum, with zero received radiation at all other wavelengths.

3.1 COLD-SOAKED BURLAP

This countermeasure used a piece of brown burlap that had been a countermeasure against visual detection of a crawling intruder the previous May, when the ground cover had been soil, thatch, and new-growth grass. For those intrusions, the burlap had been spraypainted with streaks of gray, dark brown, and green. To adapt the burlap to being a thermal countermeasure for winter use, it was wetted, sprinkled with snow, and then left outside overnight (Figure 3). The next morning the burlap was cold, and snow and ice adhered to it.

Figure 3. Cold-soaked burlap countermeasure.

With the cold-soaked burlap draped on him, the intruder moved at a high crawl from his place of concealment in brush to the perimeter chain-link fence. During the intrusion, the surface of the 6-cm-deep snowcover was warming (from –10°C at 1100 h to –7.5°C at 1200 h), as was the sky (–7.5 to –3°C); air temperature was –2°C. Thermal imagery of the intruder with and without the burlap (Figure 4) shows that it did reduce his vulnerability to thermal detection. It also provided good visual concealment (Figure 5) when the intruder was crawling across a background of shallow snowcover interrupted by tall clumps of dead alfalfa.

The advantage of this thermal countermeasure is that the material is nonreflective; otherwise, it would have reflected sky radiation toward the thermal imager. On this particular January day, the sky was colder than the snow surface from 0030 to 0900 h, with the greatest temperature difference (–26 vs. –12°C) at ~0200 h. The sky was warmer from 1000 to 1600 h and from 1830 to 2400 h. Although there were two periods on this day when the difference in temperature of the sky and snow was small enough that reflected sky radiation probably would not have been distinguishable from direct thermal radiation from the snowcover, the intruder would have had no way of predicting when those opportunities would occur.

The disadvantages of this countermeasure are that there is no insulating gap between the burlap and the intruder's clothing and that it snags on vegetation. The former means that, as the intruder exerts himself to move rapidly at a high crawl, his body heat warms the burlap. The intruder had dressed more warmly than required by the weather in an attempt to retard loss of body heat to the burlap, but this was counterproductive in that he became uncomfortably warm and sweated heavily. The draping effect of the burlap assisted in blurring the intruder's shape in both thermal and visual imagery, but it also impeded his crawl.

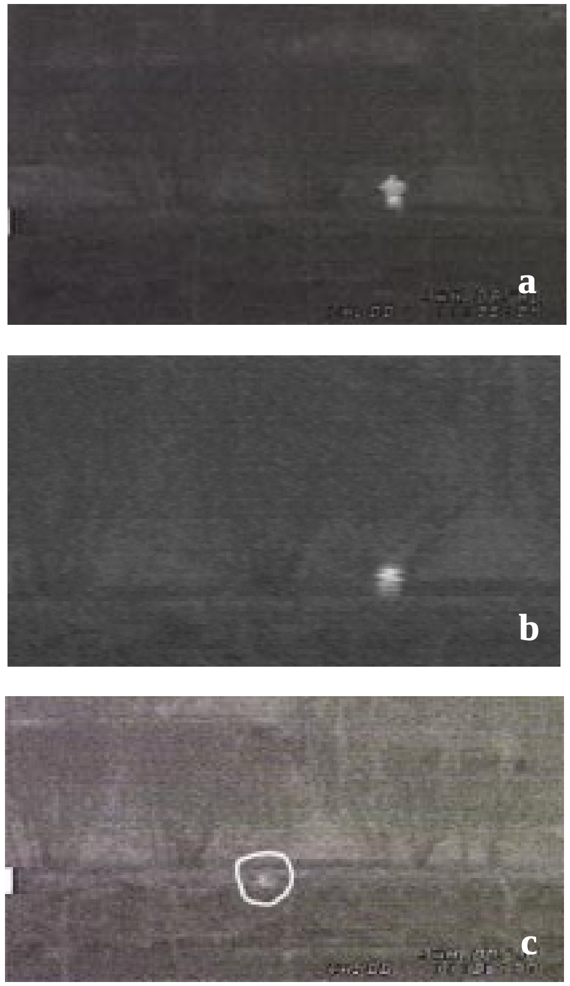

Figure 4. Thermal image (8–12 µm) of standing intruder: (a) with no countermeasures, (b) with cold-soaked burlap draped over his head and shoulders, and (c) covered with cold-soaked burlap and approaching at a high crawl; trees and brush along a river bank are visible behind him; chain-link fence posts are visible in foreground.

Figure 5. Intruder under cold-soaked burlap crossing toward the chain-link fence from river bank at high crawl.

3.2 FIRE SHELTER

This countermeasure was a commercially available fire shelter of the type used by a firefighter when a fast-moving forest fire overruns him. Its effectiveness as a countermeasure to thermal detection lies in the combination of high reflectance of incident radiation and low transmission of the sheltered person's body heat. Although lightweight and compact, the fire shelter was stiff enough to retain a general form, as in Figure 6, where it has a torpedo shape to cover a crawling intruder. Thermal images (Figure 7) of the fire shelter-covered intruder show that it can be an effective countermeasure to thermal detection.

Figure 6. Fire shelter covering low-crawling intruder.

Figure 7. Thermal image (8–12 µm) of intruder (top) under fire shelter and (bottom) sliding out from under fire shelter.

The fire shelter was used on the morning of an overcast January day. The 6-cm-deep snowcover was melting, with its surface temperature stabilized at 0°C; air temperature was 0 to 1°C. The sky and inanimate objects were approximately the same temperature, such that scenes from a thermal imager panning the site showed negligible thermal contrast unless a person (no countermeasure) was in the imager's field of view. This was a most advantageous situation for the fire shelter as a countermeasure. As the fire shelter moved with the crawling intruder, it reflected the thermal radiance of the sky and the objects it passed; but, because these were so similar in temperature to the snowcover, the change in thermal radiance was imperceptible. Intermittently, the intruder could be located in the thermal scene when his movements sometimes lifted the shelter off the snow, leaving a gap through which a portion of his high-thermal-contrast body could be seen. The fire shelter provided no concealment to visual detection.

The reflective surface of the fire shelter can be both its advantage and its disadvantage, however. Provided that there is little thermal contrast between sky and ground cover (and any other objects whose thermal radiance reflects off the fire shelter), then the fire shelter conceals the intruder from thermal detection quite successfully. This is because there is no perceptible difference between the thermal radiance of that portion of the ground incrementally covered by the crawling intruder and the thermal radiance reflected by the fire shelter to the PIR or thermal imager. But, if the sky, for example, were significantly colder or warmer than the snowcover, then the fire shelter would be readily visible in the thermal scene as a blob with the same apparent temperature as the sky, moving across a background that has the temperature of the snow surface.

3.3 VENT PIPE

The third countermeasure was different in that, rather than concealing (fire shelter) or reducing (cold-soaked burlap) the intruder's thermal signature, it altered the detection zone of the PIR. The countermeasure was made from a section of aluminum pipe attached to an aluminum clothes dryer vent (Figure 8). Special Forces soldiers created this countermeasure specifically for use against the Eltec PIR. It exploits what they regarded as a vulnerability in the design of the IDS. When the pipe was slipped over the body of the PIR, thermal radiance entering the vent opening was reflected into the PIR's thermal detectors. Once the countermeasure was in place, although the position of the PIR was unchanged, its field of view now was rotated 90° vertically. The countermeasure was slipped over the PIR from below (or above), rather than from the side, to ensure that both thermal detectors experience the change in thermal radiance simultaneously. There are two criteria for this countermeasure to be regarded as effective against thermal detection; first, it must be put in place without the PIR generating an alarm, and second, the intruders must cross the PIR's original field of view without being detected.

On the first day that the countermeasure was used, the intruders were able to position the vent pipe on the PIR without an alarm being generated. This was done by one intruder with the countermeasure mounted on a stick or by two intruders with one standing on the other's shoulders. (It is understood that at a secure facility, a PIR might be within the detection zone of a second IDS, so that approaching the PIR to install the countermeasure might require simultaneously defeating another IDS.) With the countermea-

Figure 8. Vent pipe countermeasure.

sure in place, the intruders ran undetected through the PIR's detection zone. On the next day, the intruders could not put the countermeasure in place without the PIR alarming. Although the intruders could pass undetected once the countermeasure was in place, at a secure site they should expect to have to contend with guards responding to the alarm generated while positioning the countermeasure. A possible benefit of using the countermeasure, even if an alarm is generated, is that the number of alarms (one) does not indicate the number of intruders, i.e., any number of intruders can pass undetected once the countermeasure is in place.

The intruders initially attributed their contradictory results — on day 1 the countermeasure was a success, on day 2 it was a failure — to a change in the PIR sensitivity setting apparently made while they are not at the site. The causative factor actually was the weather during the intrusions. During the first day's intrusions at dusk, a light snow was falling; air temperature was –9°C. This combination resulted in an apparent sky temperature that was only slightly lower than the surface temperature of the 28-cm-deep snowcover (–15°C vs. –12°C). The corresponding difference in thermal radiance was small enough that the PIR did not generate an alarm when reflected radiation from the sky replaced direct radiation from the snowcover at the sensor's two thermal detectors. The primary reasons for the countermeasure's success were 1) the small difference in thermal radiance between the sky and snowcover, and 2) that the change in thermal radiance was achieved at the two detectors simultaneously.

Intrusions using the countermeasure the next day involved significantly different weather conditions. The morning was clear and cold, with an air temperature of –17°C, an apparent sky temperature of –45°C, and a snow surface temperature of –22°C. The corresponding difference in thermal radiance (snowcover vs. sky) sensed by the thermal detectors as the countermeasure was positioned on the PIR was large enough that the PIR generated an alarm almost every time the intruders attempted to install the countermeasure. The unpredictability of the countermeasure's effectiveness under this day's conditions caused the intruders to abandon it. First, however, they experimented with a modified vent pipe countermeasure, which involved filling the vent pipe with snow to reduce the difference in thermal radiance incident at the detectors with and without the countermeasure in place. This approach probably would have succeeded in preventing PIR alarms but for the snow sliding out of the vent pipe as it was being angled to slide over the PIR.

Their experimentation with the snow-filled vent pipe prompted the intruders to cold-soak a panel of white Styrofoam® by placing it on the snowcover. One intruder then slowly raised the panel vertically in front of the PIR, such that the panel gradually replaced the snowcover in the fields of view of the PIR's two thermal detectors. This was accomplished without causing the PIR to alarm, which is attributed to the panel's albedo and its infrared emittance being similar to those of snow. The advantage of the panel countermeasure is that it does not require that the ground cover and the sky be closely matched in temperature for it to be effective. The disadvantage is that it must be held in place by an intruder, unlike the vent pipe countermeasure which, once in place, could be left unattended and was unobtrusive.

3.4 PONCHO SHELTER

The fourth countermeasure to thermal detection was a field-expedient shelter for a soldier on a reconnaissance or intelligence-gathering mission (Lacombe, 1989). This countermeasure relies upon the creative use of existing equipment and natural materials to conceal the soldier from visual and thermal surveillance. It consists of a standard army poncho slung between two supports and covered with snow and branches (Figures 9 and 10). The shelter is constructed with enough clearance that the poncho does not come in contact with the soldier to be warmed by his body heat. Even with the soldier inside, the surface temperature of the poncho will not exceed 0°C wherever it is covered with snow. Generally, the temperatures of the snow and branches on the poncho will be similar to those of the undisturbed snowcover and vegetation debris in the vicinity; this means that the poncho shelter itself will not be in strong thermal contrast to its background. The effectiveness of this countermeasure is evident by comparing the nighttime thermal images in Figure 11.

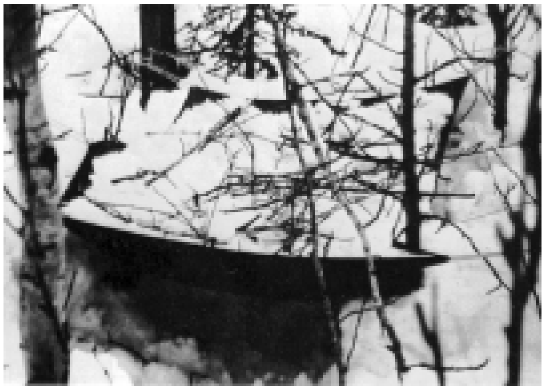

Figure 9. Poncho shelter.

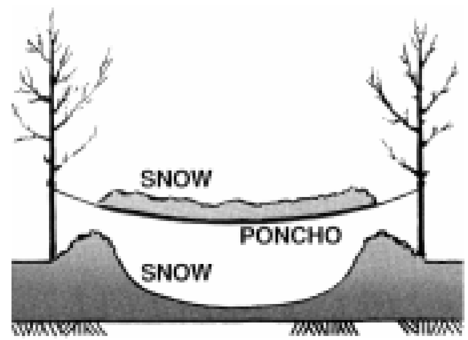

Figure 10. Design sketch of poncho and snow shelter.

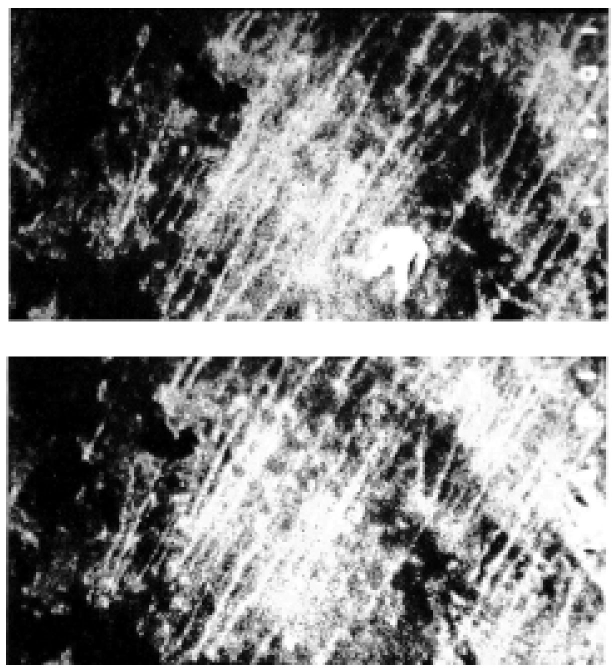

Figure 11. Nighttime thermal images (8–12 µm) of thinly wooded area containing poncho and snow shelter. An individual is standing just to the right of the shelter in the upper image. The lower image was recorded after he crawled underneath the shelter.

4.0 DISCUSSION

In addition to the weather-related influences on countermeasure effectiveness discussed above, two factors contributed to the success of the countermeasures: the state of the snowcover and the 'round-the-clock small variation in its thermal radiance (relative to other groundcovers and pavements). The PIR that the Special Forces soldiers attempted to defeat was oriented to view a triangular area that has a seasonal succession of ground covers (snow; thatch–soil–new-growth grass; uniform grasscover; dormant grass; snow). Of all the ground covers the intruders might have had to contend with at the IDS site, the snowcover was potentially the most favorable for defeating the PIR with a countermeasure, particularly during the daytime.

4.1 PIR PROXIMITY TO ALARM

The PIR's PTA depends on the temporal and spatial variability of the thermal radiance received by each of its thermal detectors. The ground cover surface temperature changes in response to absorption of solar radiation and to radiational cooling, which generally (for clear skies) follows a diurnal pattern. For a given PIR sensitivity setting, PTA under similar levels of insolation varies with ground cover because of differences in range, rate of change, and spatial variability of thermal radiance from various ground covers or pavements.

One factor in the PIR PTA during daytime is the level of insolation. This is evident in the PIR sensor response on 30 April 1992 (Figure 12; Peck, 1993) when the groundcover was thatch, soil, and new-growth grass. During the morning, the level of insolation increased from 0600 h on, with a consequent warming of the thatch–soil–grass ground cover (Figure 13). After 1300 h, the site was overcast and insolation

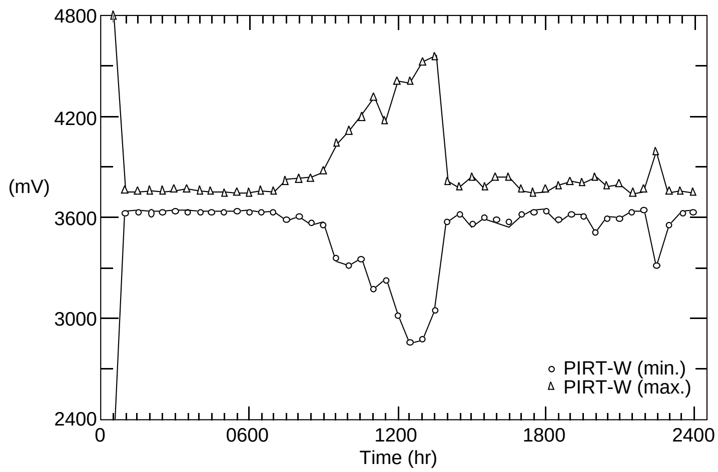

Figure 12. Time series records of PIR voltage on 30 April, 1992. Grass–thatch–soil ground cover. During daytime, strong radiant-energy heating of the ground cover ocurred through 1300 h, when the site became overcast and (average) insolation dropped from ~800 W/m^2 to ~200 W/m^2.

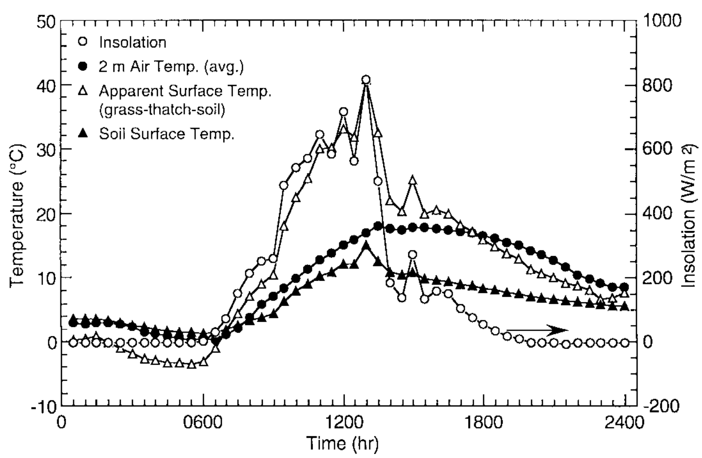

Figure 13. Time series records of air (30-min average), ground surface (calculated), and soil surface (instantaneous) temperatures and incident solar radiation (30-min average) on 30 April, 1992. Grass–thatch–soil ground cover.

dropped precipitously to levels more typical of dusk or later. The corresponding decrease in sensor response (and associated PTA) was equally abrupt and persisted into the evening. Thatch, exposed soil, and grass all respond differently to a change in insolation, depending on their albedo and thermal properties. Absorbed solar energy first dries the thatch, soil, and grass. Strong surface heating of the thatch and soil then follows, but the grass preferentially consumes the solar energy in evapotranspiration rather than in sensible heat generation. Consequently, there is both temporal and spatial variability in thermal radiance of the thatch–soil–grass ground cover within the PIR's zone, hence its PTA is high during clear-sky, daylight periods. Based on the PIR's sensitivity setting on 30 April, any time its sensor response exceeded 4100 mV or fell below 3100 mV, an alarm was generated. On this day there were 58 alarms between 1030 and 1330 h attributable to the effects of intermittent cloud cover on the surface temperature of the ground cover. These nuisance alarms could have been avoided by decreasing the PIR's sensitivity during the hours of strong insolation; however, unless the sensitivity were increased again at 1330 h, the PIR's PTA would be low from then on, providing an intruder with a favorable opportunity.

Sensor response when the PIR is viewing a continuous snowcover overlying a uniform grass cover is shown in Figure 14. PIR sensitivity was the same as on 30 April. There were no alarms in the 24 hours. The overall reduction in sensor response from 0030 h through 1030 h corresponded to warming of the snow surface from –10 to 0°C; for the remainder of that day the temperature of the snow surface was stable. PIR sensor response on other days when there is a continuous snowcover is similarly small and only slightly varying. A continuous snowcover at least 2 cm deep provides a thermally uniform background when the underlying ground cover is a mixture of thatch, soil, and short grass (Peck, 1994). A midwinter snowcover consistently is the most thermally uniform ground cover on the PIR's scale of viewing. Compared with the thatch–soil–grass groundcover, for example, the PIR's PTA is significantly lower during daytime when it is viewing a snowcover. Security personnel knowledgeable about the PIR's interaction with its environment, however, would realize that a PIR viewing a snowcover can be operated at a high sensitivity without incurring environmentally caused nuisance alarms. Increasing the PIR's sensitivity whenever its detection zone is snowcovered would make it more difficult for an intruder to avoid detection.

An estimate of the relative magnitude of PIR sensor response when viewing various groundcovers or pavements can be obtained by comparing the magnitudes and rates of change of their surface temperatures. Daily maximum surface temperatures on sunny days are listed in Table 1 for the sequence of snowcover, thatch–soil–grass, and grasscover at the IDS site and for gravel, grass, sand, concrete, and asphalt at CRREL. The corresponding daily ranges in surface temperatures and typical rates of change of surface temperature are also listed. The surface temperature of pavements and ground covers (other

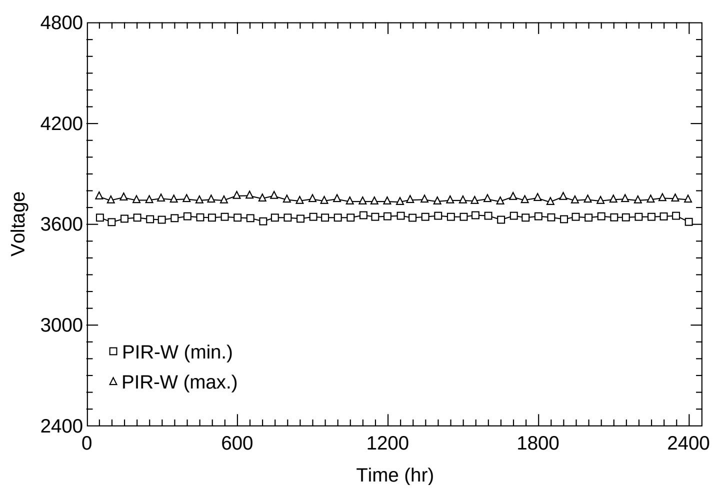

Figure 14. Time series record of PIR voltages when 2- to 4-cm-deep continuous snow layer covered ground.

than snow) generally shows a diurnal pattern that mirrors the insolation cycle, with the exception that the temperature of a snowcovered or wet surface is moderated by the consumption of solar energy in melting the snow or evaporating moisture, respectively. The surface temperature of a snowcover depends on the magnitude of the available solar energy only while there is no melting; it stabilizes at 0℃ during melting. A late-winter snowcover potentially is more dynamic than a midwinter snowcover due to the greater likelihood for significant warming during the course of a day (Peck, 1996). Table 2 presents the approximate thermal radiance (in the spectral band 8–14 μm) emitted by a ground cover at selected surface temperatures. The equation to convert temperature to thermal radiance, $N = 1.876 \times 10^{-11} * T^{5.032}$, where T is in Kelvin, was obtained from Planck's equation for the specific spectral band of 8 – 14 μm; it is valid over the temperature range –50 to 50℃ and for a surface with emissivity of 1. From Table 2 it is evident that a 1℃ change in temperature of a summer grasscover at midday (e.g., 40 to 41℃) typically causes twice the change in thermal radiance sensed by the PIR's thermal detectors that a 1℃ change in temperature of a snowcover does (e.g., –10 to –9℃). This means that a small mismatch in temperature between countermeasure and background is more significant under nonwinter conditions when the associated difference in thermal radiation is greater.

Table 1. Surface temperature maxima, daily range, and rates of change.

Surface	Maximum surface temperature (°C)	Daily range [maximum – minimum] (°C)	Maximum rate of change [absolute value] (°C / hr)	Months
Midwinter snow	–1.9 to 0	1 to 12	4	Jan, Feb
Late winter snow	0	22 to 25	10	Mar
Thatch–soil–grass	21 to 41	29 to 45	20	Apr, May
Summer grass	32 to 45	23 to 37	10	Jun
Autumn grass	16 to 24	22 to 26	10	Sep, Oct
Dormant grass	–1 to 7	9 to 13	5	Dec, Jan
Crushed gravel*	17 to 29	5 to 16	9	Jul
Grass*	21 to 36	7 to 25	11	Jul
Sand*	20 to 48	8 to 37	16	Jul
Concrete*	21 to 34	7 to 21	6	Jul
Asphalt*	23 to 52	7 to 37	16	Jul

* Lower values correspond to a day of overcast sky and rain

Table 2. Change in thermal (8–14 μm) radiance attributable to 1°C change in ground cover surface temperature.

Initial		Final		
Temp (°C)	Radiance (W / m² sr)	Temp (°C)	Radiance (W / m² sr)	ΔRadiance (W / m² sr)
–30	19.01	–29	19.41	0.40
–20	23.29	–19	23.75	0.46
–10	28.30	–9	28.83	0.54
0	34.14	1	34.78	0.64
10	40.91	11	41.64	0.73
20	48.72	21	49.56	0.84
30	57.68	31	58.64	0.96
40	67.91	41	69.01	1.10
50	79.53	51	80.78	1.25

4.2 OTHER SNOWCOVER FACTORS RELEVANT TO INTRUDER SUCCESS

As discussed above, a continuous, undisturbed snowcover presents a thermally uniform background to an imager or PIR. If the intruder disturbs the snowcover by leaving footprints or crawl marks, however, that uniformity is interrupted proportionately to the thermal gradient between the base of the snow layer (ground surface) and the snow surface. The sign and magnitude of the thermal gradient depend on current weather conditions and the thermal history of the snowcover, but it is not unusual for the snowcover's base to be warmer than its surface. This means that an intruder who successfully conceals himself with a countermeasure that mimics the surface temperature of the snow may leave behind a trail that is in strong thermal contrast with the snow surface.

On the days of the intrusions using the cold-soaked burlap and the fire shelter, the snowcover was shallow (6 cm deep) and firm, such that CRREL personnel did not leave noticeable footprints. Because each intruder moved at a crawl (low crawling under the fire shelter, high crawling under the burlap), any disturbance to the snowcover was subsequently made indistinct by the trailing portion of the countermeasure. No disturbance persisted in the thermal imagery to indicate the intruder's path. If the intruder sinks into the snow, however, then he would be at risk for detection. He is vulnerable not because his countermeasure fails, but because his path of disturbed snow is marked by its thermal contrast with the undisturbed snowcover.

When the Special Forces soldiers were at the site another time, the snowcover was deeper (19 cm) and the top 16 cm was a layer of newly fallen snow. Foot traffic was excluded from certain areas of the IDS site to provide an undisturbed snowcover as a background for the intruders' activities. The first intruder to crawl through the PIR's detection zone left a trench almost as deep as his body thickness (Figure 15). He also tried to use his passage to mound snow on the side toward the PIR as a means of concealing himself behind a berm of snow. Both he (no countermeasure) and his trail were in high thermal contrast with the cold surface of the undisturbed snowcover (Figure 16). The PIR alarmed on the lead intruder, but it did not detect intruders who crawled behind him. This is attributed to the low thermal contrast between the following intruders and the relatively warm snow at depth that was exposed at the trench made by the first intruder's passage.

Figure 15. Two intruders crawling through PIR's detection zone. Second intruder uses trench created by first intruder's passage through the 19-cm-deep snow.

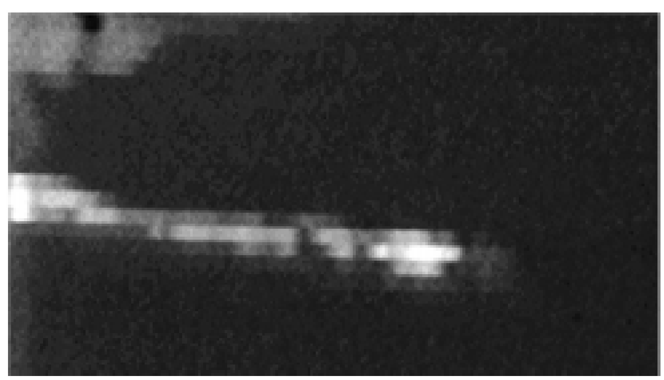

Figure 16. Thermal image (8–12 μm) of lead intruder in Figure 15 as he crawls through the detection zones of the two PIRs.

If the first intruder were using the vent pipe countermeasure against the PIR under favorable weather conditions (when the sky and snow surface temperatures are in close agreement), then he likely would avoid detection by the PIR; however, he would leave behind evidence of his intrusion in the form of footprints or a trench. Wiping out the tracks might adequately conceal them from visual detection, but the greater disturbance to the snowcover would be more noticeable in a thermal image; how noticeable the disturbance is and how long it persists depend on the weather and the thermal gradient within the snow layer. Even after the snow surface appears undisturbed to the eye because subsequently the footprints are filled in with fallen or blown snow, the intruder's trail may still be noticeable in a thermal image. Because the thermal conductivity of snow depends on its density, heat flow through the snow layer will be different where the intruders' footsteps have compacted the snow.

5.0 CONCLUSIONS

Compared with other ground covers and with pavements, a snowcover presents certain advantages to an intruder attempting to avoid thermal detection though the use of countermeasures. Because the surface temperature of a snowcover typically has a smaller diurnal range and actually is stabilized (0°C) during snowmelt, it is a less dynamic thermal background for the intruder to blend with. Because a passive infrared intrusion detection system viewing a snowcover experiences smaller natural variations in thermal radiance, the intruder may have a larger margin between detection and nondetection; unless, that is, the PIR's sensitivity has been increased specifically because the PIR is viewing a snowcover.

A snowcover presents two fundamental disadvantages. The first is that the thermal contrast between a person and a cold snowcover can be quite large, so the countermeasure has to work very well for it to be at all effective. The second is that the snowcover may retain a record that an intrusion has occurred, in the form of tracks in the snow, even if the intruder himself has avoided detection.

Four countermeasures have been described: two rely on matching the temperature of their background (cold-soaked burlap; poncho shelter) and two rely on substituting reflected thermal radiance for that of the intruder (fire shelter; vent pipe). The latter are more weather dependent in that the countermeasures only succeed if the reflected thermal radiance is indistinguishable from that of the background. Based on the results reported here, intruders and security personnel should be alert to situations of overcast sky and melting snowcover.

6.0 ACKNOWLEDGMENTS

This study was jointly funded by the U.S. Army Corps of Engineers and the U.S. Air Force Electronic Systems Center, Force Protection Directorate. CPT Thomas Gilligan, Dr. George Koenig, and James Morse provided technical reviews.

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